



UNIVERSITY
OF WOLLONGONG
AUSTRALIA

University of Wollongong
Research Online

Australian Institute for Innovative Materials - Papers

Australian Institute for Innovative Materials

2018

3D printing Vegemite and Marmite: redefining "breadboards"

Charles Hamilton

University of Wollongong, cah170@uowmail.edu.au

Gursel Alici

University of Wollongong, gursel@uow.edu.au

Marc in het Panhuis

University of Wollongong, panhuis@uow.edu.au

Publication Details

Hamilton, C. Alan., Alici, G. & in het Panhuis, M. (2018). 3D printing Vegemite and Marmite: redefining "breadboards". *Journal of Food Engineering*, 220 83-88.

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library:
research-pubs@uow.edu.au

3D printing Vegemite and Marmite: redefining "breadboards"

Abstract

The ability to use Food Layered Manufacturing (FLM) to fabricate attractive food presentations and incorporate additives that can alter texture, nutrition, color, and flavor have made it widely investigated for combatting various issues in the food industry. For a food item to be FLM compatible, it must possess suitable rheological properties to allow for its extrusion and to keep its 3D printed structure. Here, we present a rheological analysis of two commercially available breakfast spreads, Vegemite and Marmite, and show their compatibility with FLM in producing 3D structures onto bread substrates. Furthermore, we demonstrated that these materials can be used to fabricate attractive food designs that can be used for educational activities. The inherent conductivity of the breakfast spreads was used to print edible circuits onto a "breadboard."

Disciplines

Engineering | Physical Sciences and Mathematics

Publication Details

Hamilton, C. Alan., Alici, G. & in het Panhuis, M. (2018). 3D printing Vegemite and Marmite: redefining "breadboards". *Journal of Food Engineering*, 220 83-88.

3D Printing Vegemite and Marmite: Redefining “Breadboards”

Charles Alan Hamilton^{1, 2}, Gursel Alici^{1, 3}, and Marc in het Panhuis^{1, 2,*}

¹ Intelligent Polymer Research Institute, ARC Centre of Excellence for Electromaterials Science, AIIM Facility, University of Wollongong, Wollongong, NSW 2522, Australia

² Soft Materials Group, School of Chemistry, University of Wollongong, Wollongong, NSW 2522, Australia

³ School of Mechanical, Materials and Mechatronic Engineering, University of Wollongong, Wollongong, NSW 2522, Australia

* Author to whom correspondence should be addressed: panhuis@uow.edu.au

Abstract

The ability to use Food Layered Manufacturing (FLM) to fabricate attractive food presentations and incorporate additives that can alter texture, nutrition, color, and flavor have made it widely investigated for combatting various issues in the food industry. For a food item to be FLM compatible, it must possess suitable rheological properties to allow for its extrusion and to keep its 3D printed structure. Here, we present a rheological analysis of two commercially available breakfast spreads, Vegemite and Marmite, and show their compatibility with FLM in producing 3D structures onto bread substrates. Furthermore, we demonstrated that these materials can be used to fabricate attractive food designs that can be used for educational activities. The inherent conductivity of the breakfast spreads was used to print edible circuits onto a “breadboard.”

Keywords: Vegemite, Marmite, Rheology, 3D Printing, Edible, Circuit

1. Introduction

There is a constant need for innovative methods of food processing to address various problems in caring for those with specialized dietary needs. Physiological changes that occur with aging such as dysphagia, decreased sensory perception, and changing nutritional needs require the elderly to have specialized diets [2]. Consequently, many elderly patients in hospitals and long-term care facilities suffer from underdiagnosed malnutrition, which causes comorbidities in the patients [3]. Other groups, such as children, have specialized dietary requirements and studies have been conducted to determine methods to ensure children eat balanced meals. An effective method to meet their nutritional needs has been arranging food into attractive presentations and it has been reported that children prefer to eat a wider variety of food if it is plated in a fun and appealing way [4]. There is also a call for new food manufacturing techniques to satisfy the food-based desires of astronauts who have their

gustation altered due to the environment in the line of duty. The mental health and morale of astronauts is critical for successful completion of their long-term missions and it is reported that they crave good food more than other comforts [5]. Recently, 3D printing has been explored as an innovative food-manufacturing technique that has the ability to meet these special dietary requirements.

3D printing is an additive manufacturing technique that involves the layer-by-layer deposition of materials to form a 3D structure that may not have been achievable with conventional manufacturing techniques. Coined “Food Layered Manufacturing” (FLM), 3D printing showed its first application in the food industry with the development and use of the extrusion-based Fab@home system [6-9]. Most extrusion-based systems consist of a syringe containing a viscous material that is hooked up to a nozzle that is able to move with 3 degrees of freedom. The material is then pushed out of the syringe by either pneumatic pressure or a piston to deposit material layer-by-layer until a 3D shape is formed [6, 10].

FLM has been used to print edible materials into complex shapes and gives the user the ability to modify properties like texture, colour, flavour, and nutrition. It has also been used to fabricate conductive devices using edible materials that may eventually play a role in future novel drug delivery systems and GI monitoring devices [11]. A wide range of materials have been printed, including cake frosting, processed cheese, meat purees, chocolate, dough, and more [8-10, 12-14]. FLM allows these materials to be fabricated into attractive food presentations that can incorporate multiple materials and additives to enhance nutrient value catered to individual needs. Depending on the food that is created, it can either be cooked by various post-processing methods and still retain its structure or remain soft to meet texture requirements of an individual unable to consume hard food [12, 15]. All of this provides a tremendous platform of opportunity for schools, parents, food service managers, child care centres, old age homes, and food manufacturers to incorporate this technology into their production lines to combat malnutrition and address specific dietary needs of different demographics [4, 13, 14]. In order for a food material to be compatible with FLM, it must possess suitable rheological characteristics to allow for its extrusion. In the future, an in depth understanding of the rheological properties of food materials for their use in FLM will be critical, especially when considering the rheological effects of certain additives [16].

In this study, we present a rheological analysis of commercially available Australian breakfast spreads, Vegemite and Marmite, and demonstrate their compatibility with FLM

through the creation of attractive food designs printed onto edible (bread) substrates. Furthermore, we show how the rheological properties of these spreads can be modified and how the resolution and integrity of the printed structures are affected. Lastly, we use the inherent electrical conductivity of the breakfast spreads to fabricate edible circuitry through the creation of a “breadboard.” This example of conductive food patterning is used to demonstrate the potential of FLM and commercially available food products in edible electronics and as a learning tool for students during outreach activities.

2. Materials and Methods

Vegemite and Marmite, produced by Mendeley International and Sanitarium Health Food Company, respectively, were purchased from Woolworths Supermarkets (Wollongong, Australia) and used without any further modification. The edible white bread substrate, also purchased from Woolworths, was modified before use by slight downward pressure by hand (using a rectangular acrylic plate) to create a flatter substrate. Following this, the bread was inserted in a typical household toaster (HomeMaker T358 Bread Toaster) until golden brown. The bread was left to equilibrate to room temperature (21 °C) prior to any printing.

2.1 Rheological Characterization

Rheological characterization of Vegemite and Marmite were conducted on an Anton-Paar Physica MCR 301 Digital Rheometer with a conical plate measuring system (49.972 mm diameter, 0.992° angle, 97 µm truncation) and a heat-controlled sample stage (Julabo Compact Recirculating Cooler AWC 100). Temperature sweeps of Vegemite and Marmite were done at a constant shear rate of 100 s⁻¹ while decreasing the temperature from 40 °C to 4 °C at a rate of 2 °C/min.

Viscosity profiles of Vegemite and Marmite were obtained at temperatures of 4, 10, 20, and 37 °C by ramping the shear rate ($\dot{\gamma}$) from 0.1 – 500 s⁻¹. The apparent viscosity was measured and plotted as a function of the shear rate. The resultant curve was modeled to a power law (Eq. 1), and used to calculate the consistency (K) and power law index (n) of the materials at different temperatures:

$$\eta = K\dot{\gamma}^{n-1} \quad . \quad (1)$$

The shear stress (σ) was plotted as a function of the shear rate and a Bingham model was used to determine the yield stress (σ_y) as follows:

$$\sigma = \sigma_y + \eta\dot{\gamma} \quad . \quad (2)$$

96

97 **2.2 3D Printed Structures**

98 3D printed structures of Vegemite and Marmite were fabricated onto edible (bread)
99 substrates using a commercially available BioBot 1 extrusion printer purchased from BioBots
100 and controlled with the Repetier Host software. A pyramid structure (base of 3cm x 3cm) was
101 modeled in SolidWorks 2016 and exported as a .STL file that was subsequently sliced with
102 Slic3r, converted to Gcode, and loaded into Repetier Host. The pyramid was printed with
103 Vegemite and Marmite onto toasted bread at temperatures of 25 and 45 °C, respectively.

104 **2.3 Direct Writing of Attractive Food Presentations**

105 Attractive food presentations of Vegemite and Marmite were printed onto edible
106 bread substrates at 25°C using the BioBot printer. Images of a smiley face, a fish, and a stick
107 figure were created using Solidworks and uploaded to the printer as described above.

108 **2.4 Edible Circuits**

109 The edible circuits were printed onto the bread substrates using a custom made 3D
110 printer based on a CNC milling machine and controlled by LinuxCNC software. Sets of
111 Gcode were written in a Linux Gedit program and Vegemite or Marmite was extruded out of
112 a 5mL syringe by a T-NA08A25 Zaber linear actuator. After printing, red, yellow, and green
113 LEDs purchased from Jaycar Electronics (Wollongong, Australia) were added. The
114 “breadboard” was connected to a power supply set to 12V to represent the lights at a traffic
115 stop.

116 **3. Results & Discussion**

117 **3.1 Rheology**

118 Rheological studies were used to look into suitable viscosities for the 3D printing of
119 Vegemite and Marmite into shapes that can retain their structure post-printing. The
120 temperature profiles of Vegemite and Marmite, (Figure 1), show the expected behavior of
121 decreasing viscosity (η at constant shear rate) with increasing temperature. It was observed
122 that the behavior can be modeled to a power law (data not shown).

123

124

125

To understand the flow behavior of Vegemite and Marmite, viscosity profiles (shown in Figure 2) were measured at varying temperatures and fit to a power law shown in Eq. 1, where η is the viscosity, $\dot{\gamma}$ is the shear rate, K is defined as the flow consistency index, and n as the flow behavior exponent.

The flow behavior exponent and consistency behavior index are especially important in determining if a material is compatible with FLM and determining the desired extrusion rates. The flow consistency indices of Vegemite and Marmite represent the viscosity of the material at a shear rate of 1 s^{-1} and decrease with rising temperature as would be expected (see Table 1). Flow behavior exponents less than 1 indicate that both Vegemite and Marmite are shear-thinning materials. For Marmite, this value decreases with decreasing temperature, indicating an increase in shear-thinning behavior and a further deviation from Newtonian fluid behavior.

When plotting the shear stress versus the shear rate (see Figure 2), the material exhibited pseudoplastic behavior and a Bingham model (Eq. 2) was used to determine the yield point, σ_y , of the materials at varying temperatures (see Table 1).

An observed yield point can be explained by the presence of particulates throughout the material that form a stabilizing network. Once the applied pressure is large enough to break this network, the yield point has been overcome and the material will begin to flow like a liquid (think the amount of “squeezing” necessary before toothpaste begins to flow out of a tube). The existence of a yield point and the minimum pressure needed to overcome it is a very important parameter that must be tuned for each material in FLM, especially when using pneumatically driven printing systems.

Our results indicate that, in general, Vegemite has lower yield points than Marmite (Table 1). In other words, less pressure is required to start the extrusion process of Vegemite compared to Marmite. As expected, the yield point decreases significantly with increasing temperature and appears to follow exponential behavior.

3.2 Dependence of Print Quality on Viscosity

Understanding how rheological properties of food materials will influence resultant printed 3D structures will be critical as FLM continues to find additional applications. Here, we demonstrate the use of commercially available Vegemite and Marmite in the fabrication of 3D structures and attractive food presentations. We also show how the integrity of the printed structure depends on the rheological properties of the materials.

159

160 **3.2.1 3D Printed Structures**

161 To demonstrate the use of Vegemite and Marmite with FLM techniques, a pyramid
162 was printed at temperatures of 25 and 45 °C (see Figure 3). The substrate used was toasted
163 bread to replicate the usual circumstances under which the breakfast spreads are usually
164 consumed. All print conditions were kept constant aside from the pneumatic pressure used to
165 extrude the materials. At 25 °C, 25 psi (172 kPa) of pressure was used to extrude both
166 materials but needed to be decreased to 15 psi (103 kPa) to print the structures at 45°C. When
167 attempting to use 25 psi (172 kPa) to print the structures at 45 °C, the flow rate was too large
168 and the printed structure resembled a puddle of material. When attempting to print the
169 structure at a higher temperature of 65 °C, the material was extruded too quickly even with
170 very low pressures (<5 psi or 34 kPa) being used to extrude the material. It was observed that
171 Vegemite and Marmite retained the integrity of the printed structures at 25°C much better
172 than at 45°C. This demonstrates that the breakfast spreads possess rheological characteristics
173 that are compatible with FLM techniques. In other words, it is possible to 3D print self-
174 supporting structures in Vegemite and Marmite (at temperatures below 45 °C).

175 **3.2.2 Attractive Food Presentations**

176 An attractive food presentation is beneficial in a wide range of applications, and could
177 soon become an easily accessible commodity in modern households with advances in FLM.
178 We show that commercially available Vegemite and Marmite can be used to create fun
179 designs suitable for celebratory events such as birthday parties. Similar to the 3D structures
180 presented above, the designs were printed onto toasted and buttered bread to simulate
181 conditions under which the FLM product would be consumed. Vegemite and Marmite were
182 both found to possess suitable rheological characteristics to print the attractive designs
183 (Figure 4).

184

185 **3.3 Edible Electronics – Redefining Breadboards**

186 We have routinely used printed 3D structures on bread in our educational activities.
187 For example, during a visit to a daycare center, attractive food presentations were used to
188 teach children about 3D printing technologies (see Figure 5). It was observed that the
189 fabrication of food into designs is favored greatly by the younger children, and serves as a

great method for encouraging them to consume healthy food and get engaged in educational activities.

We observed that Vegemite and Marmite are able to conduct DC electricity due to the presence of salt ions. Vegemite and Marmite were found to exhibit conductivity values of 20 ± 3 S/cm and 13 ± 1 S/cm, respectively (data not shown). We demonstrated that Vegemite and Marmite can be used to make circuits resulting in the fabrication of a literal “breadboard.”

The potential to use commercially available food products to create electronic circuits has enabled us to create fun educational outreach activities. For example, here we present a Vegemite circuit consisting of a red, yellow, and green LED to simulate a traffic light (Figure 6). Similar results could be obtained using Marmite (data not shown). After the experiment, the non-edible metal circuit components (LEDs & wires to power supply) were removed and the edible components of the “breadboard” (Vegemite/Marmite & toasted bread) were consumed either by the authors or by children during educational activities. Videos of our functioning circuits can be found in the supplementary information and online [17].

4. Conclusion

In this paper, we have shown that the compatibility of commercially available food products, Vegemite and Marmite, with FLM techniques can be used to produce 3D structures, such as attractive food designs and edible circuitry onto bread substrates. We demonstrated the importance of characterising the rheological behaviour of the food products in retaining the structural integrity of the printed materials (e.g. pyramids on bread). The electrical conductivity of Vegemite and Marmite was used to print edible circuits on “breadboards.” It was shown that printed FLM designs are suitable in outreach activities to teach young learners about electronic circuits and 3D printing.

Our work contributes to the development of food processing techniques that have the potential to be used in a wide range of applications such as space missions, aged-care facilities, and hospitals. FLM has a lot to offer for these applications due to the potential to modify flavour, nutrition, and texture through the incorporation of combinations of food additives. In addition, FLM can be used to fabricate food into attractive designs suitable for special occasions such as children birthday parties.

Acknowledgements

This work was supported by funding from the University of Wollongong (UOW) and the Australian Research Council (ARC) Centre of Excellence for Electromaterials Science. We thank Chris Richards and Dr. Steve Beirne from the Materials Node of the Australian National Fabrication Facility (ANFF) at UOW for the use of the BioBot printer. Reece Gately and Alex Keller are thanked for assistance with electrical characterisation.

References

1. Wan, H., G. Daniel, and K. Paul, *An Aging World: 2015*. 2016, United States Census Bureau: International Population Reports.
2. Goldman, A., et al., *Meeting the Food Needs of the Ageing Population - Implications for Food Science and Technology*, in *Scientific Information Bulletin*, T.I.U.o.F.S.a. Technology, Editor. 2014.
3. Wells, J.L. and A.C. Dumbrell, *Nutrition and aging: assessment and treatment of compromised nutritional status in frail elderly patients*. *Clinical Interventions in Aging*, 2006. **1**(1): p. 67-79.
4. Zampollo, F., et al., *Food plating preferences of children: the importance of presentation on desire for diversity*. *Acta Paediatr*, 2012. **101**(1): p. 61-6.
5. Terfansky, M.L. and M. Thangavelu, *3D Printing of Food for Space Missions*, in *AIAA SPACE 2013 Conference and Exposition*. 2013, SPACE Conferences and Exposition: San Diego, California.
6. Wegrzyn, T.F., M. Golding, and R.H. Archer, *Food Layered Manufacture: A new process for constructing solid foods*. *Trends in Food Science & Technology*, 2012. **27**(2): p. 66-72.
7. Malone, E. and H. Lipson, *Fab@Home: the personal desktop fabricator kit*. *Rapid Prototyping Journal*, 2007. **13**(4): p. 245-255.
8. Periard, D., et al. *Printing Food*. in *Proceedings of the 18th solid freeform fabrication symposium*. 2007. Austin, Texas.
9. Lipton, J.I., et al., *Additive manufacturing for the food industry*. *Trends in Food Science & Technology*, 2015. **43**(1): p. 114-123.
10. Godoi, F.C., S. Prakash, and B.R. Bhandari, *3d printing technologies applied for food design: Status and prospects*. *Journal of Food Engineering*, 2016. **179**: p. 44-54.
11. Keller, A., et al., *3D Printed Edible Hydrogel Electrodes*. *MRS Advances*, 2015. **1**(8): p. 527-532.
12. Lipton, J., et al., *Multi-Material Food Printing with Complex Internal Structure Suitable for Conventional Post-Processing*, in *21st Solid Freeform Fabrication Symposium*. 2010: Austin, Texas. p. 809-815.
13. Sun, J., et al., *A Review on 3D Printing for Customized Food Fabrication*. *Procedia Manufacturing*, 2015. **1**: p. 308-319.
14. Sun, J., et al., *An Overview of 3D Printing Technologies for Food Fabrication*. *Food and Bioprocess Technology*, 2015. **8**(8): p. 1605-1615.
15. Goulbourne, N.C., et al., *3D jet printer of edible gels for food creation*. 2014. **9058**: p. 90580A.

- 264 16. Fischer, P. and E.J. Windhab, *Rheology of food materials*. Current Opinion in Colloid &
 265 Interface Science, 2011. **16**(1): p. 36-40.
 266 17. <https://www.youtube.com/watch?v=TpCDg69hj1E>

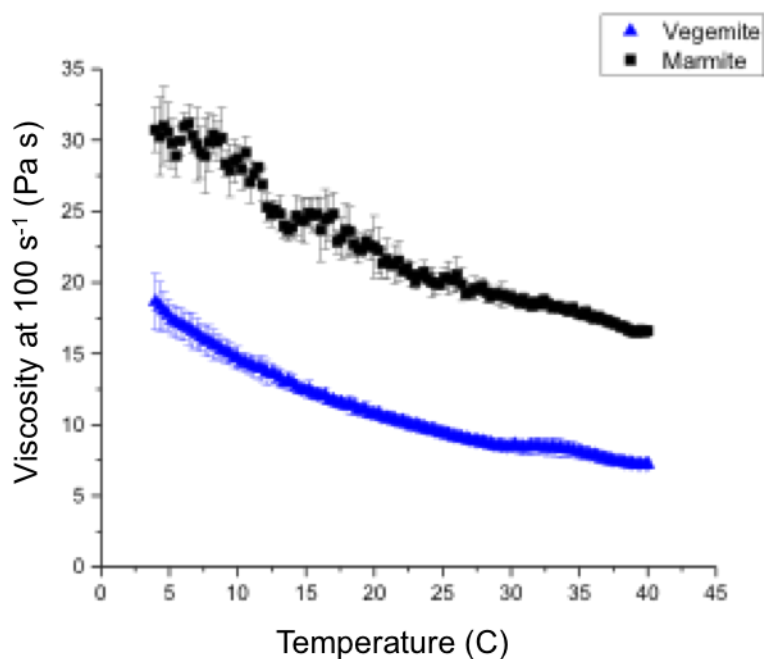


Figure 1: Temperature sweep of Vegemite (blue triangles) and Marmite (black squares) from 40 – 4 °C at 2 °C/min with a constant shear rate of 100 s⁻¹.

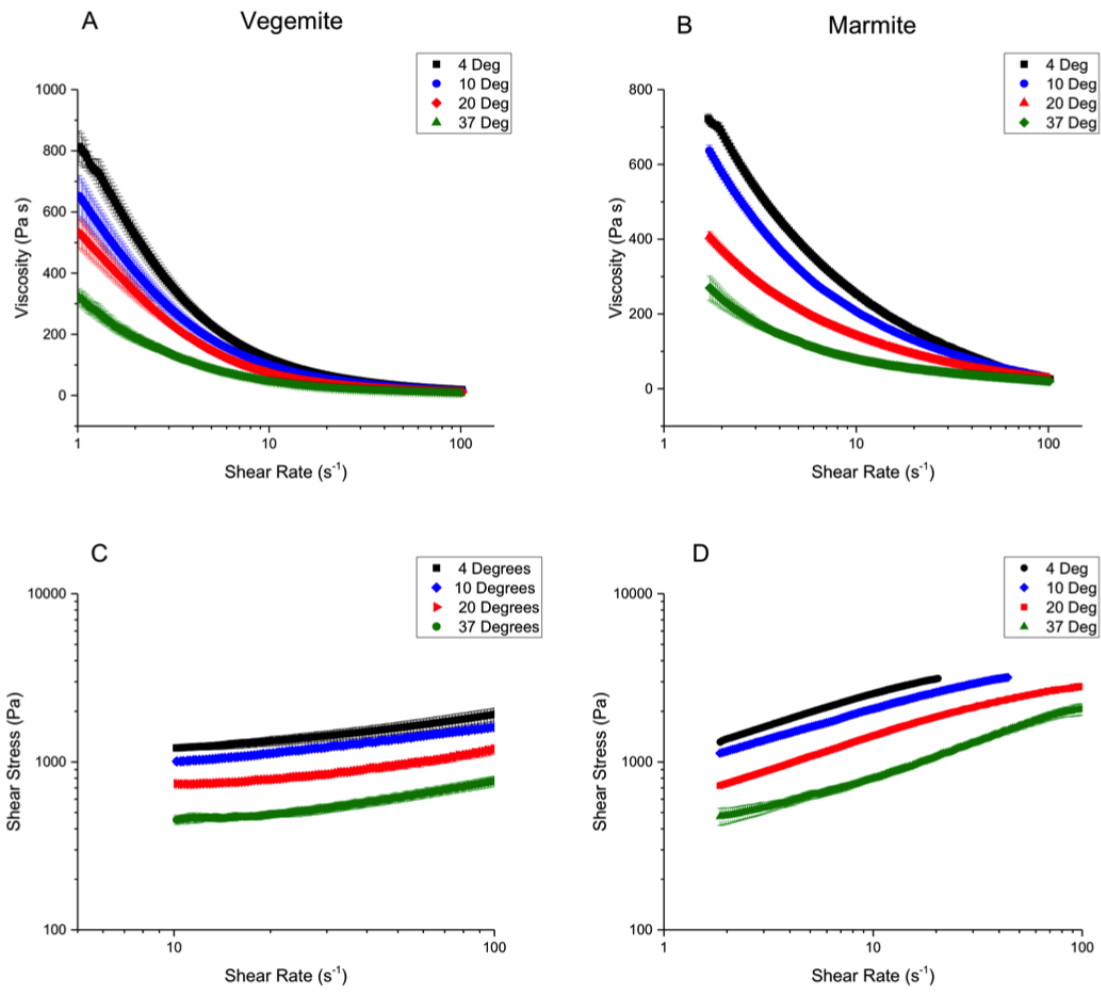


Figure 2: Viscosity profiles of (A) Vegemite and (B) Marmite at 4 °C (black squares), 10 °C (blue spheres), 20 °C (red diamonds), and 37 °C (green triangles). Shear Stress versus Shear Rate of (C) Vegemite and (D) Marmite at 4 °C, 10 °C, 20 °C, and 37 °C. Error bars shown but may not be visible.

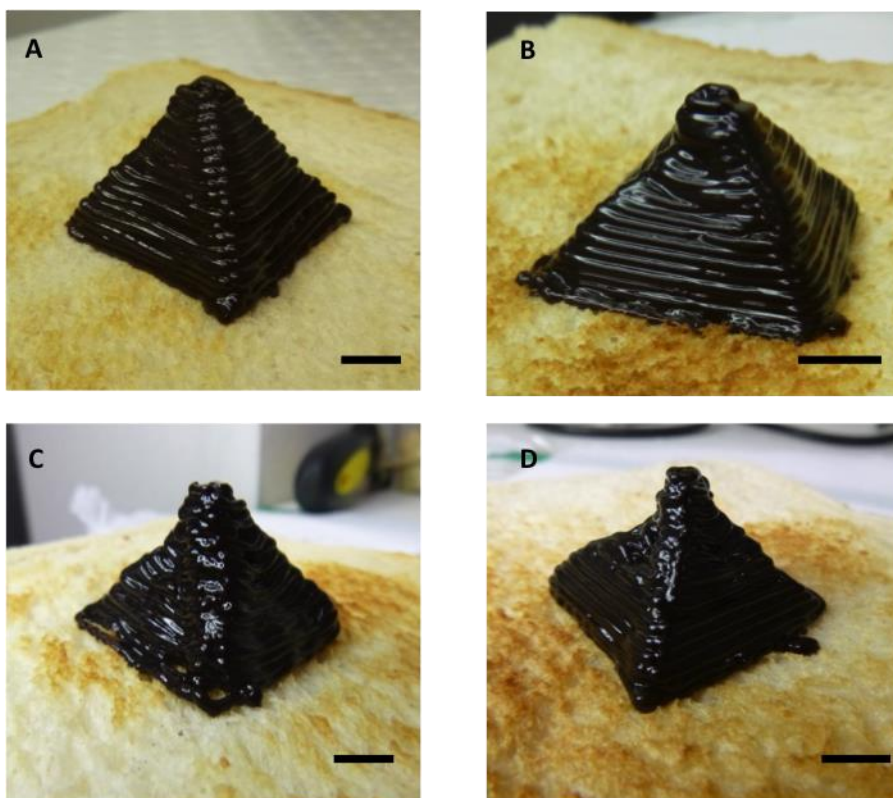


Figure 3: Photographs of Vegemite and Marmite printed into pyramid shapes on toasted bread. (A) Vegemite printed at 25 ° C, (B) Vegemite printed at 45 °C, (C) Marmite printed at 25 ° C, and (D) Marmite printed at 45 °C. All scale bars shown are 1cm in length.

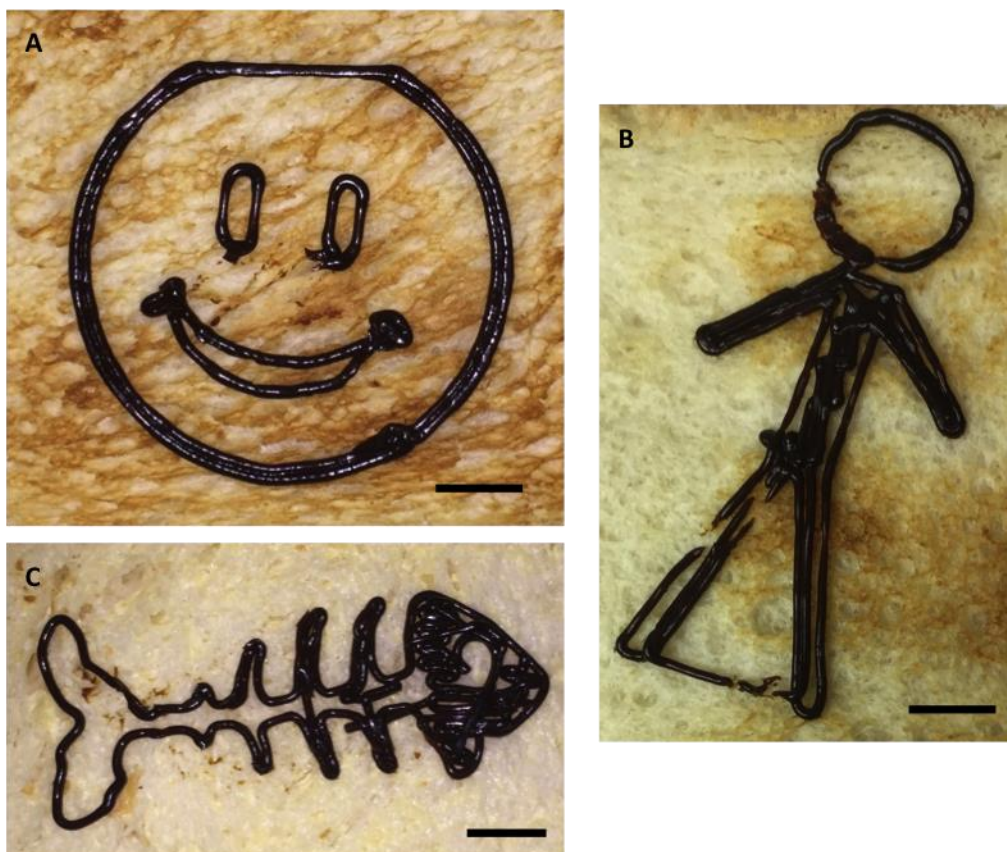


Figure 4: Photographs of 3D printed designs of (A) Vegemite smiley face on toasted bread, (B) Marmite stick figure on toasted bread, and (C) Vegemite fish on buttered bread (C). All scale bars shown are 1cm in length.



Figure 5: Photographs of educational activities. (A) Children crowd around a 3D printer being used to print designs in Vegemite, and (B) child looking at the 3D printed Vegemite “UOW” letters on a piece of bread.

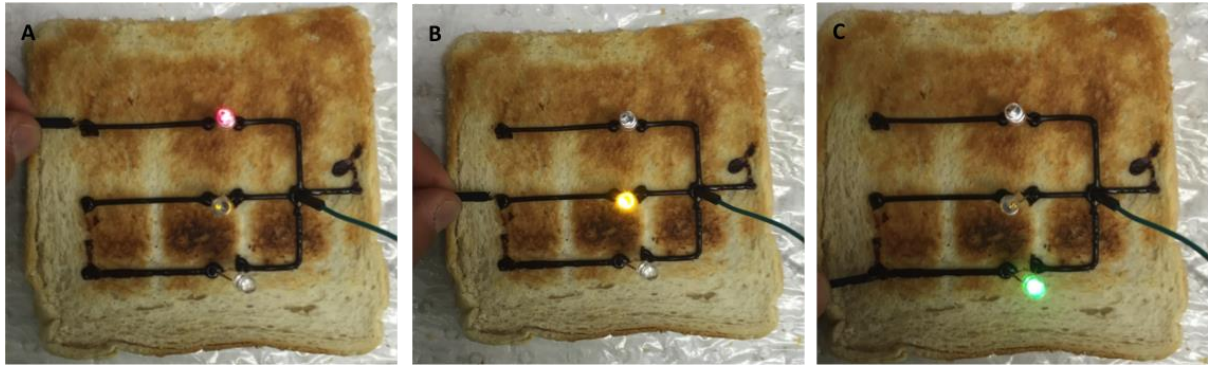


Figure 6: Photographs of a 3D printed Vegemite electronic circuit extruded onto edible (bread) substrate, simulating the (A) red, (B) yellow, and (C) green lights of a traffic light.

Table 1: The rheological parameters (including standard deviations) of Vegemite and Marmite at various temperatures where σ_y represents the yield stress, K represents the flow consistency index, and n represents the flow behaviour index.

	Vegemite			Marmite		
Temp (°C)	σ_y (Pa)	K (Pa s ⁿ)	n	σ_y (Pa)	K (Pa s ⁿ)	n
37	419 ± 2	333 ± 27	0.154 ± .006	595 ± 12	340 ± 26	0.39 ± .01
20	687 ± 2	590 ± 35	0.121 ± .005	1095 ± 26	608 ± 20	0.356 ± .004
10	987 ± 6	697 ± 69	0.17 ± .02	1364 ± 25	1014 ± 11	0.291 ± .010
4	1168 ± 5	905 ± 49	0.144 ± .005	1419 ± 25	1378 ± 2	0.22 ± .013